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Numerical Simulation of Damage and Fracture in Concrete from Shaped Charge Jets

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Numerical Simulation of Damage and Fracture in Concrete from Shaped Charge Jets[1]

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ABSTRACT

This paper addresses numerical simulation of damage and fracture in concrete from the impact and penetration of shaped charge jets. We have modeled the jet penetration process with CALE, a two dimensional arbitrary Lagrange eulerian hydrocode. We have looked at several constitutive models ranging from simple pressure dependent yield to more complex deviatoric models that include the effects of dilatency. Evaluation of the concrete material models is based on comparison to experimental results of an aluminum lined shaped charge fired against a high strength concrete target at several standoff distances.

1. INTRODUCTION

The objective of this paper is to review and evaluate material models used in the simulation of shaped charge jet penetration in concrete. The simulations are compared to experimental results of a baseline shaped charge fired into high strength concrete at 1 to 4 CD standoff. We have looked at several constitutive models ranging from simple pressure dependent yield to more complex deviatoric models that include the effects of dilatency. Our ultimate goal in this work is to develop a straight forward material model that a) describes the unbroken material, b) determines when the material breaks, and describes the broken material.

2. SHAPED CHARGE DESCRIPTION

The baseline shaped charge used for our experimental studies is shown in Figure 1. This charge has a 105 degree, 4% thick, 6061-t6 aluminum liner. This charge is the same or very similar to shaped charges used in several of our other concrete target penetration studies and analysis [1-3]. The charge has a diameter of 109 mm with a l/d of 1. It is has a thin aluminum case, plastic rear cover, and is loaded with LX-14. Detasheet is used to burn around the foam wave shaper for peripheral initiation. This class of charge, independently developed at LLNL in 1980, is known as the X-Charge. Charges of similar design have been known as X-Charges since the early 60's Kennedy [4] and more recently as the K-Charge at Primex Technologies[5].

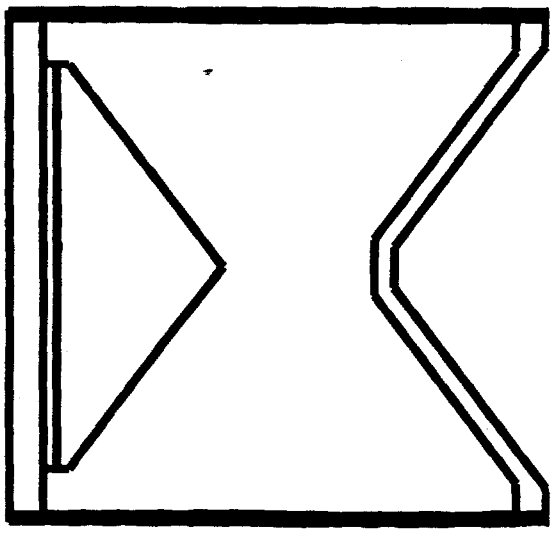

Figure 1. Baseline Shaped Charge

[1] Work performed under the auspices of the U.S. Department of Energy by the Lawrence Livermore National Laboratory under Contract W-7405-Eng-48.

3.0 EXPERIMENTAL RESULTS

Experimental results of penetration versus standoff into high strength (0.6 GPa) heavily reinforced concrete are shown in Figures 2 & 3. The first four hole profiles (left to right) shown in Figure 2 were conducted at 1, 2, 3, & 4 cd standoff. The fifth hole profile was a repeat of the 3 CD experiment, showing an example of the variability of concrete target penetration. The penetration versus standoff results are shown in the upper curve of Figure 3. Note that the 3 CD repeat experiment is not shown.

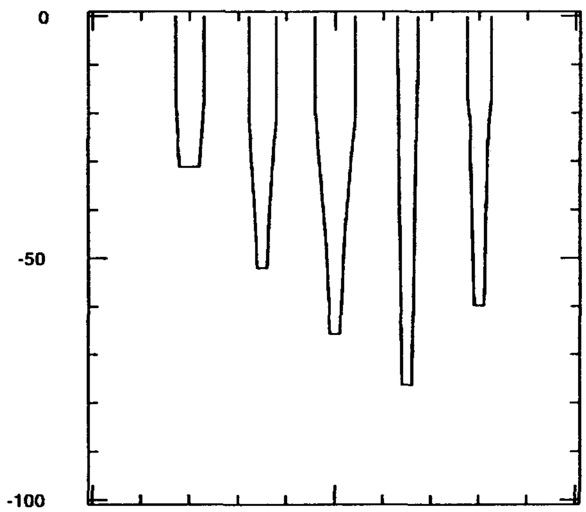

Figure 2. Hole profile versus standoff.

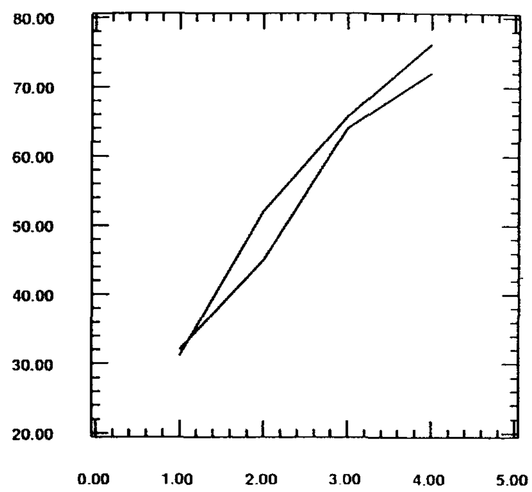

Figure 3. Penetration (CD) vs standoff (CD).

4. MODELING STUDIES

The CALE [6] simulation of the jet formation from the LLNL X-Charge is shown in Figure 4. A unique feature of this class of charges is the high tail velocity (about 2 km/sec). All of the mass in the liner is projected forward and is considered part of the jet. The "slug" typically seen with narrow angle liners and point initiated charges is not observed in the X-Charge simulations or experiments. All of this jet contributes to penetration because of the high tail velocity and large diameter holes created.

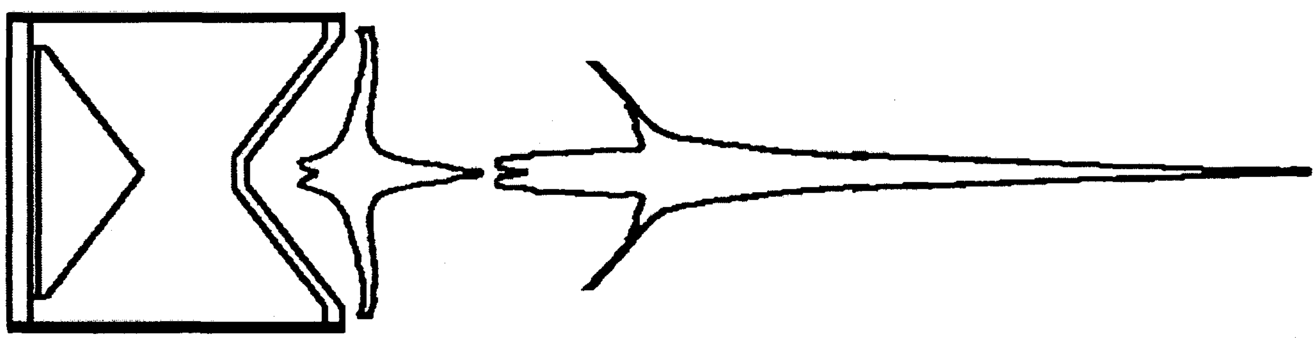

Figure 4. X-Charge jet formation showing high tail velocity and no slug development.

The primary objective of the modeling studies described in the remainder of the paper are to investigate the sensitivity of the calculated jet penetration to the material properties and material models used to describe the aluminum liner and concrete target.

4.1 Baseline Penetration Analysis

The penetration versus standoff analysis was conducted using the JWL EOS for the LX-14 [7], Steinberg-Guinan model for the Aluminum liner [8], and the CALE TEPLA-F Porous Metal EOS (adapted for concrete). The TEPLA-F porous metal EOS was designed for porous metals but has also been successfully adapted for use with other porous materials such as sand and concrete. It uses a polynomial form pressure versus volume relationship for the solid (referenced to the tmd) with the porous pressure equal to the solid pressure times (1.0 – porosity). The concrete density was 2.3 g/cc with TMD of 2.6 g/cc resulting in an initial porosity of 11.5 percent. The yield surface for the "5 ksi" concrete was modeled with pressure dependence and a maximum yield strength of 0.168 GPa. The results of the baseline simulations of penetration versus standoff are shown in the lower curve of Figure 3. These baseline simulations are in fairly good agreement with the experimental results and are certainly within the experimental error. The 2 CD standoff simulation experiment showed the greatest deviation from the experimental result and was selected as the standoff to use for further aluminum and concrete material model sensitivity studies.

4.2 Penetration at 2 CD as a Function of Liner Strength

Simulation of the 2 CD penetration (cm) as a function of the aluminum liner material strength (GPa) is show in Figure 5. These studies were first conducted to determine the sensitivity of the calculated penetration to liner material strength. Previous modeling studies with EFP's indicate the necessity to calibrate the "text book" values for the material strength of explosively loaded thin plates [9]. This plot spans the range of results from low strength, high purity and annealed 1100-O Al to high strength, alloyed, and tempered 6061-t6 Al. The wide variation in penetration depth as a function of jet strength is primarily due to the magnitude of the elongation of the tail of the jet during the late stages of the collapse.

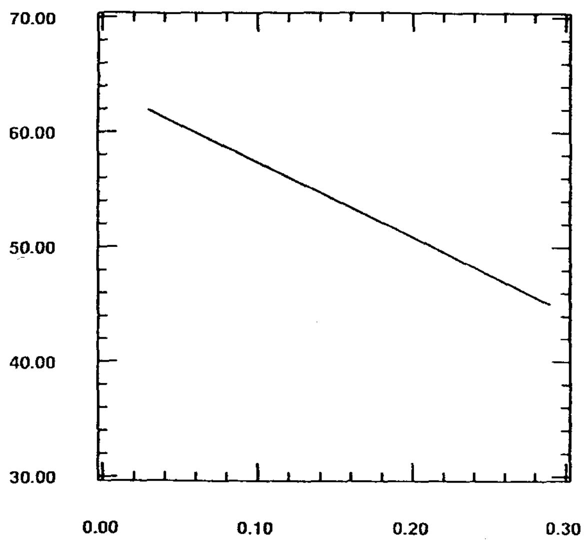

Figure 5. Penetration (cm) vs jet strength (GPa).

4.3 Penetration at 2 CD as a Function of Target Density

The result of the simulations of penetration (cm) at 2 CD as a function of target density (g/cc) is shown in Figure 6. The EOS and theoretical maximum density (TMD) of the target material was held constant at 2.6 g/cc in these simulations. The simulation density of the target material was varied from 2.0 to 2.6 with a corresponding change in the porosity.

4.4 Penetration at 2 CD as a Function of Target Porosity

The result of the simulations of penetration at 2 CD as a function of target porosity is shown in Figure 7. The simulation density of the target material was held constant in these runs at a value of 2.3 g/cc. The TMD for the concrete was varied from 2.3 g/cc (0% porosity) to 2.6 g/cc (11% porosity).

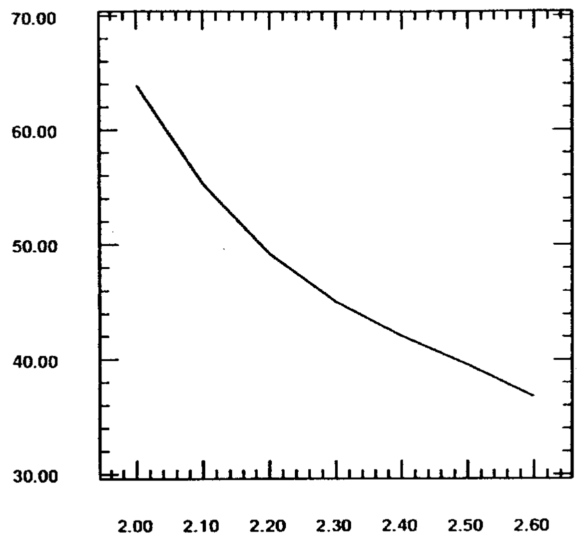

Figure 6. Penetration (cm) vs density (g/cc).

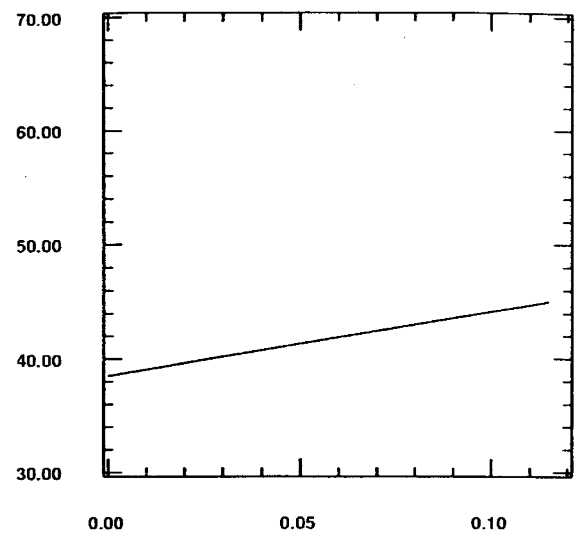

Figure 7. Penetration (cm) vs porosity (%).

4.5 Penetration as a Function of Target Dilatency

During the initial phase of the jet interaction with the concrete target the primary bulk material response of the concrete is void closure. The initial volume of the concrete target material decreases as the pressure field from the jet/target interaction closes initial voids. A subsequent volume increase from unloading is modeled by the "baseline" pressure vs volume EOS while a volume increases from fracture can be treated by a separate EOS of the fractured material. If the volume increase from fracture & unloading is greater than the volume decrease from compression and pore collapse, then a net dilatency effect is observed. Concrete has been shown to behave with dilatency [10,11].

For our initial assessment of the effects of dilatency we decided to evaluate the Cagnaux-Glenn model used previously for Pyrex glass [12-14] and the simplified Maxwell-Winer Bulking Model [15]. Failure of the concrete was based on tensile pressure in the Cagnaux-Glenn model and on a critical threshold level for expanded material. The preliminary results of these simulations are not conclusive on whether it is necessary to consider the effects of dilatency in the simulation of aluminum jets penetration high strength concrete. Regardless of the failure threshold level, if it was at a level that allowed failure, then we observed a 10% penetration reduction is all simulations. We would expect a variation in this value as a function of the level at which failure occurs. Further investigation of this phenomena is planned.

4.6 Hole Diameter as a Function of Target Strength

The result of the simulations of target hole diameter (cm) at 2 CD as a function of target strength (GPa) is shown in Figure 8. These results show the hole diameter is linearly dependent on the strength of the concrete target. The results of the simulations showed no change in the depth of penetration as a function of the target strength.

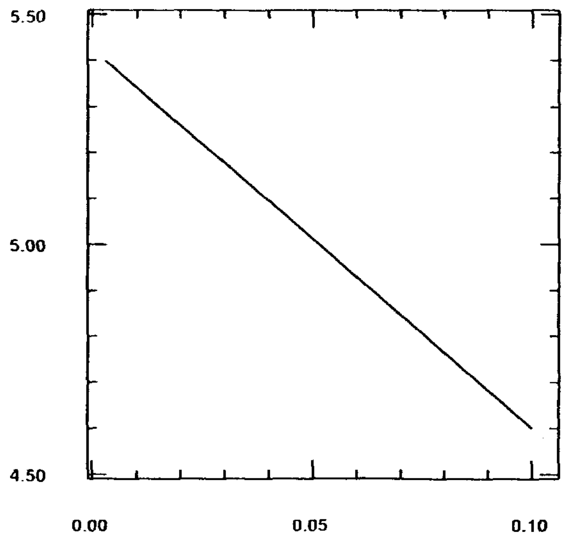

Figure 8. Hole diameter (cm) vs strength (GPa).

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